

## ***Interactive comment on “Oxygen and carbon isotope composition of modern planktic foraminifera and near-surface waters in the Fram Strait (Arctic Ocean) – a case-study” by T. Pados et al.***

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Received and published: 16 January 2015

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1. Comment: My main concern is with the discussion on the offset between  $\delta^{13}\text{C}_{\text{calcite}}$  and  $\delta^{13}\text{C}_{\text{DIC}}$ . Pados et al. discuss several reasons for this offset and suggest that the  $[\text{CO}_3^{2-}]$  may be an important parameter. However, they ignore the possibility of a temperature effect on the  $\Delta\delta^{13}\text{C}$ , which has been observed in culture studies (Bemis et al., 2000) and potentially also in field studies on *N. pachyderma* (Jonkers et al.,

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2013b). It would be a significant improvement to the study if the authors attempted to quantify both effects on the  $\delta^{13}\text{C}_{\text{calcite}}$ . A temperature effect can readily be evaluated and since no carbonate system data exists for the ARK XXVI/1 cruise I suggest the authors make use of data that is available in the CARINA and GLODAP databases (some is also accessible through ODV) to obtain first order estimate.

Author's response and changes in the manuscript: We thank Lukas Jonkers for his valuable suggestion, which also in our opinion would improve the manuscript. Therefore, we have included the evaluation of the temperature effect on the offset between  $\delta^{13}\text{C}_{\text{calcite}}$  and  $\delta^{13}\text{C}_{\text{DIC}}$  and also evaluated the vertical carbonate ion distribution in the area, by extracting data from the CARINA database.

2. Comment: It would also be valuable if the comparison with previous studies in the Fram Strait was more extensive. Perhaps add a figure comparing the different studies. And an additional reference that could be used for this purpose is Stangeew (2001).

Author's response and changes in the manuscript: We have picked up Jonker's suggestion and included an additional figure comparing our results to those of Volkmann and Mensch (2001) and Stangeew (2001), showing  $\delta^{18}\text{O}$  of *N. pachyderma* (sin.) from the water column and the equilibrium calcite values in the upper water column (Fig. 10). In the manuscript text we have made reference to this figure in the appropriate places. Moreover, we have added a short paragraph to the discussion of  $\delta^{13}\text{C}$ , discussing the different vital effects reported by Volkmann and Mensch (2001) and Stangeew (2001) from the same area.

3. Comment: Vital effect: the offset from equilibrium  $\delta^{18}\text{O}$  of course depends on the paleotemperature equation that is used to calculate  $\delta^{18}\text{O}_{\text{eq}}$ . This needs to be highlighted and also means that the estimate of the vital effect derived by Jonkers et al. (2010), which is based on the Kim & O'Neil (1997), needs to be adjusted before it can be compared to the other estimates (see also Jonkers et al., (2013a)).

Author's response and changes in the manuscript: Jonkers is right. However, in this

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case, the adjustment does not change the validity of the respective sentence (that the offsets reported in Jonkers et al., 2010 are smaller than in our study). Nevertheless, we have changed the reference to Jonkers et al., 2013 where the authors mention the same vital effect calculated with the paleotemperature equation of Shackleton (1974) modified after O'Neil (1969).

4. Comment: *T. quinqueloba* data: it is worthy showing these if they are potentially unreliable due to low amounts of calcite? At the very least, this major caveat needs to be stressed again in the discussion of  $\delta^{13}\text{C}$ .

Author's response and changes in the manuscript: We try to be honest when we state that the scatter observed in the *T. quinqueloba* data may at least partly result from the low amounts of calcite in the samples and not always represent natural variation of the  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  values. Nevertheless, we think the data should be documented, if only for a comparison with future studies. Unless the editor suggests to remove the figure (Fig. 8 in the original manuscript, Fig. 9 in the revised version) we prefer to keep it in the paper and mention the described inaccuracy again in the discussion chapter.

5. Comment: Seasonality: both *N. pachyderma* and *T. quinqueloba* have a growing season that is significantly longer than a month in summer (Jensen, 1998; Jonkers et al., 2010, Kohfeld et al., 1996). The fossil signal will therefore not only reflect maximum temperatures during summer, but integrate the entire growing season and hence incorporate lower temperatures as well. This could also help to explain the difference between the (snap)shot plankton tow data and the sediment data.

Author's response and changes in the manuscript: To our knowledge, the timing and length of the growing seasons of *N. pachyderma* and *T. quinqueloba* in ice-covered and seasonally open waters are still somewhat elusive. Kohfeld et al. (1996) report on maximum fluxes in a 2 week-long bloom event at the beginning of August (in the Northeast Water Polynya). Similar observations were made by Wolfteich (1994) on the Iceland Plateau. On the other hand, in the Irminger Sea the growing season seems

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to be much longer (Jonkers et al., 2010). One may speculate that seasonally and interannually variable factors (ice drift, arrival of the ice margin at the particular stations, remaining coverage by patchy sea ice) play an important role, and from our limited database it seems impossible to draw conclusions in the length of the growing season (it would also go beyond the scope of our manuscript). Nevertheless, we thank Jonkers for his comment, which we gratefully pick up and mention the length of the growing season as one of the unknowns in our manuscript. In the end, however, we can only stick with a comparison of what we have: data from the water column and from the sea floor...

6. Comment: Effect of eddies and temporal temperature variability: how sensible is it to compare shell chemistry to snapshots of hydrography when foraminifera reflect ambient water conditions over their entire life span? Part of the offsets between water column and test  $\delta^{18}\text{O}$  and  $\delta^{13}\text{C}$  could potentially be explained by mesoscale variability (which is visible in Fig. 2). In addition the estimates of advection distance (Von Gyldefeldt et al., 2000) represent only the sinking phase (i.e. after death of the foram). During its life stage, a test can be advected over greater lengths.

Author's response and changes in the manuscript: Lukas Jonkers' comment touches a weakness of all studies so far using plankton tows and water samplers: both instruments always reveal the situation only at the time of sampling. Ideally (to get full insight into the system), samples should be obtained every two weeks or so at exactly the same positions along a transect, again and again over a time period of several months – an effort that is so demanding on shiptime that has not been performed in the Fram Strait or other places in the Nordic Seas, at least to our knowledge. For the moment, we have to live with snapshot data of foraminifers and can compare them to water data from the same day and to what we know about intraseasonal variability. We agree that such mesoscale variability might also influence the offset between the isotope values of the water column and the foraminifera samples. However, the temperature anomalies that are revealed from Figure 2 are not reflected in the offsets

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found at the same locations. Mesoscale variability may thus play a role but this is hard to estimate based on the available data. Nevertheless, we have included mesoscale variability as a potential factor in the revised version of the manuscript. Regarding the possible transport of foraminifers over long distances, we cannot exclude this possibility. However, if transport would play a large role, we would then expect a more or less systematic offset of foraminifer and equilibrium calcite  $\delta^{18}\text{O}$  along our transect, in particular for *T. quinqueloba*, which is more likely to be advected from the south than the polar *N. pachyderma* (which actually shows such a systematic offset, although for other reasons, as discussed in the text). One would expect that in the east *T.q.* and equilibrium calcite values are less different from each other than in the west where waters are much colder and accordingly the offset should be larger if the *T.q.* had spent a large part of their lifespan in warm Atlantic waters. In fact, there is no such systematic offset visible from Fig. 8 and thus, we refrain from considering long-range transport of foraminifers an important factor. Nevertheless, we have rephrased the text slightly so that transport effects are not fully excluded.

7. Comment: For comparison with the sediment data it would be useful to also plot the weighted mean isotope data in Fig 7 and 8.

Author's response and changes in the manuscript: We thank Jonkers for this suggestion, which we gladly pick up. However, we think that additional data points in figs. 7 and 8 (Fig. 5 and 9 in the revised version of the manuscript) will not improve the clarity of these figures. Instead, we prefer to add one more figure (Fig. 8 in the revised version), which compares the data from the surface samples and the weighted means of foraminifer isotope values from the water column. In the manuscript text we have made reference to this figure in the appropriate places.

8. Comment: Sea ice and vital effect: the observation of a variable vital effect is very interesting and deserves more attention, as this crucial information for paleoceanographers. While I cannot offer an explanation for this variability I would like to point out that the highest concentration of *N. pachyderma* (or of planktonic foraminifera, for that

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matter) was found in sea ice: up to 320 #/L! (Spindler and Dieckmann, 1986). Perhaps sea ice does therefore not represent unfavourable conditions.

Author's response: We are aware of the results of Spindler and Dieckmann (1986), but to our knowledge *N. pachyderma* has never been found in Arctic sea ice in significant amounts. We thus refrain from far-reaching speculations here. Instead we stick to own observations (Pados & Spielhagen, 2014) and those of others working in the area that in the Fram Strait the absolute abundances of planktic foraminifera in the upper water column decrease significantly under the sea ice compared to the conditions at the sea ice margin. Even if we do not know the ultimate reason for this, we simply conclude from this observation that the water column under sea ice cover represents favourable conditions.

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Interactive comment on Biogeosciences Discuss., 11, 8635, 2014.

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